El Dorado TMDL Five Year Review: 2008

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Summary: In 2002 the Kansas Department of Health and Environment developed a pair of high priority TMDLs for the El Dorado Lake watershed, covering siltation and eutrophication. A regularly scheduled five-year review of the status of this waterbody shows that water quality has declined relative to the period prior to 2002, and limited implementation of new management efforts has commenced. However, any conclusions about the causes of the change in water quality are limited by the twin impacts of zebra mussels (*Dreissena polymorpha*) and an extended drought occurring during the most recent two sampling events. Some additional studies have been completed to better characterize the status of El Dorado Lake, and these results suggest that the lake would benefit from additional conservation measures in the watershed. Effective implementation of additional conservation measures could benefit from lake users, including public water supplies, providing additional funding to supplement cost-share programs and preserve this asset for future water supply and recreational uses. We recommend that this water body continue to receive regular monitoring by state personnel, and that the users of this lake look into developing a more comprehensive set of monitoring tools to better understand changes in the lake's capacity and trophic state.

Issues-

Siltation- The 2002 siltation TMDL was developed to protect the lake from the loss of capacity (and associated eutrophication) caused by delivery of soils and other solids into the lake. Calculation of siltation rates is complicated by the diverging estimates of original storage capacity at conservation pool. A recently completed Oklahoma Water Resources Board (OWRB) report on the bathymetry of El Dorado Lake used an original design document conservation pool estimate of storage capacity at 154,100 acre-feet. The Kansas Water Office (KWO) has estimated original conservation pool storage capacity at 163,942 acre-feet. The 2002 TMDL quoted 163,929 acre-feet as the original conservation pool capacity. The practical result of these diverging estimates is that storage loss estimates are probably best estimated based on the 1989 bathymetric survey of El Dorado Lake, which estimated at that time that 161,929 acre-feet of cumulative storage existed at the top of the conservation pool (1,339 ft above sea level). Furthermore, future estimates of sedimentation rates may be improved by comparison to the 2005 OWRB report, which estimates current storage capacity at 158,630 acre-feet.

Using the 1989 and 2005 surveys shows an average annual loss of capacity of 206 acre-feet per year ((161,929-158,630)/(2005-1989)), which exceeds original design specifications of 134 acre-feet/year by 54% as an annual average. We note here that the TMDL used a guidance of 174 acre-feet of storage loss per year. The source of this figure is unclear, but the KWO fact sheet on the lake quotes 134 acre-feet/year from the Corps of Engineers (CoE) for designed loss of storage due to siltation. If we instead use the 1981 survey, the results are slightly worse, showing 221 acre-feet/year storage loss, exceeding original design specifications by 65% as an annual average. Using the more conservative estimate based on the 1989 survey, which includes both very wet years and very dry years, the sediment storage capacity of El Dorado Lake will be filled in 2049, 35 years ahead of design specifications (Figure 1). At current rates the conservation pool will take 769 years to fill with sediment.

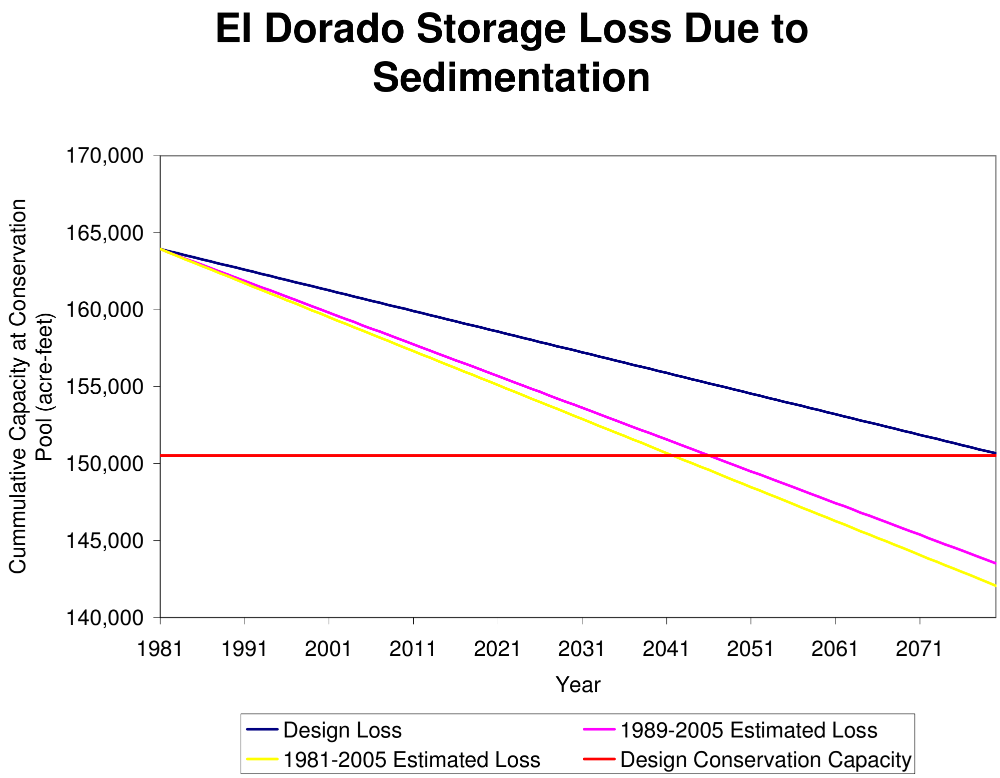

Figure 1- Estimates of storage loss in El Dorado Lake due to siltation. Design life for the sediment pool is based on a 100 year capacity at 134 acre feet per year. Estimates of filling rates are explained in the text.

The OWRB report shows that capacity loss due to filling is largely confined to the historic channels of the streams feeding El Dorado Lake and the uppermost reaches of the three arms of the lake. Some exceptionally shallow areas are located upstream of constrictions in the lake where elevated road surfaces create effective sediment traps. The main basin of the lake has largely been unchanged by siltation.

Identifying sources of sediment can prove more challenging than estimates of storage capacity loss because most sediment moves during infrequent, high volume runoff events (Figures 2 and 3) which are not captured by any sampling programs currently being used at El Dorado Lake. The Tulsa CoE office developed a Soil and Water Assessment Tool (SWAT) model to identify major sources of sediment and nutrients entering into El Dorado Lake. This model estimated that upland sources of sediment were likely to contribute 19,039 metric tonnes of sediment per year to the lake. Using the same 66 lbs/foot^3 weight measurement reported in the model results, the measured loss of capacity for the 1989-2005 period is 269,000 metric tonnes per year. The 2002 TMDL used a bulk density estimate of 58 lb/s foot^3, resulting in an estimated annual load of 236,000 metric tonnes per year. However, using an estimate of 20 lbs/foot^3 for newly deposited sediment from Simons & Sentürk (1992), we generate an estimate of 81,500 metric tones per year (Figure 4). Some settling of deposited sediment is expected to occur over time, so a better estimate of the volume of sediment to El Dorado Lake will still leave some uncertainty regarding the load of sediment entering the lake each year. With these uncertainties in mind, estimates of future volume loss and the results of improvements to management practices would benefit from a more accurate characterization of sediment weight, bulk density and in-lake settling over time. These results suggest that the model has significant error, which the report authors attribute to in-channel degradation and bank erosion.

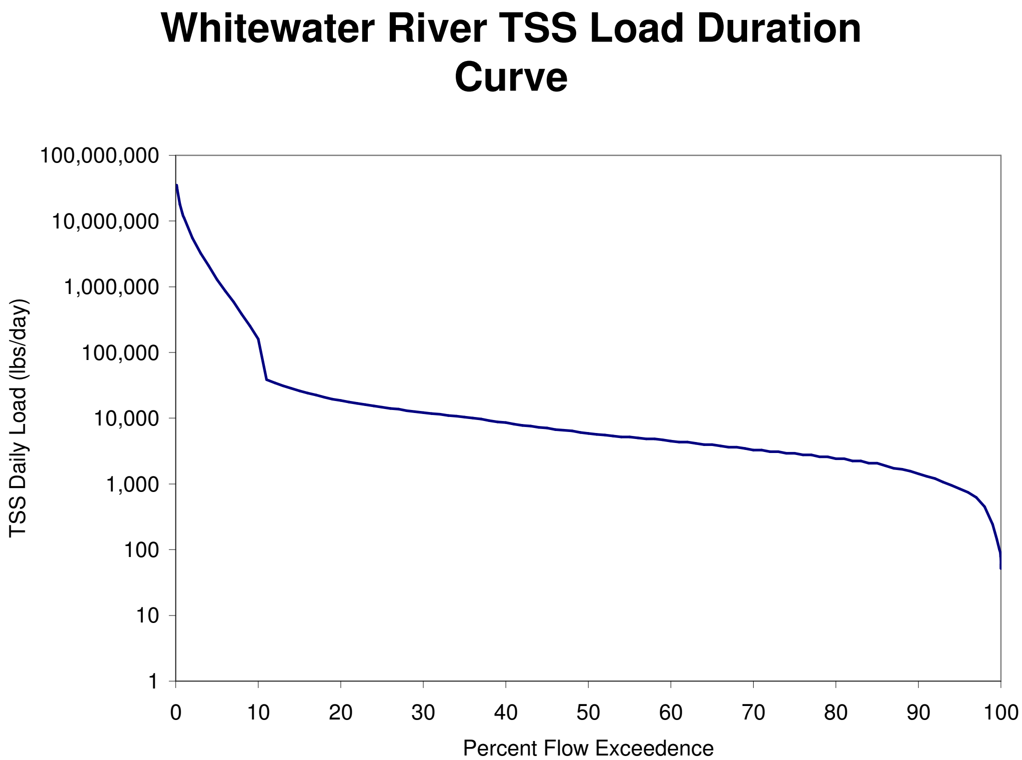

Figure 2- A nearby example stream showing the estimated TSS load by percent exceedence. Low flows, which are likely to be met or exceeded most of the time, have higher percent exceedence flow values. At a flow likely to be met or exceeded about 10% of the time a shift in loading occurs resulting in increased concentrations along with exponentially increasing flows, resulting in significantly larger total loads during these infrequent flow events. See Figure 3 for the cumulative results of this effect over a year.

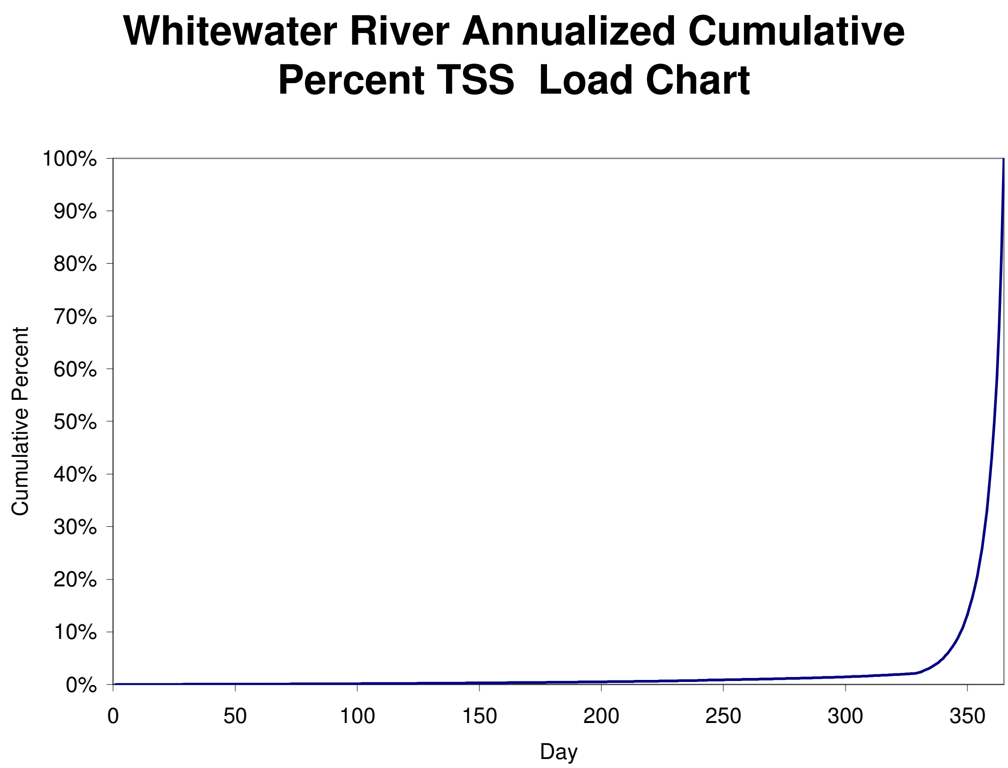

Figure 3- By averaging annual flow data over 30 years and converting the percent flow exceedences into a 365 step scale we can create an average year that approximates the conditions over the 30 year period. Multiplying the daily flow for each day, starting at the smallest flow and working up to the largest flow, by the estimated concentration at that flow we generate an estimated daily load. Summing all days generates a cumulative annual load. The individual daily loads are divided by the cumulative annual load, as presented here. The largest percentage of the total annual load occurs during relatively few days, those with high flows and high concentrations.

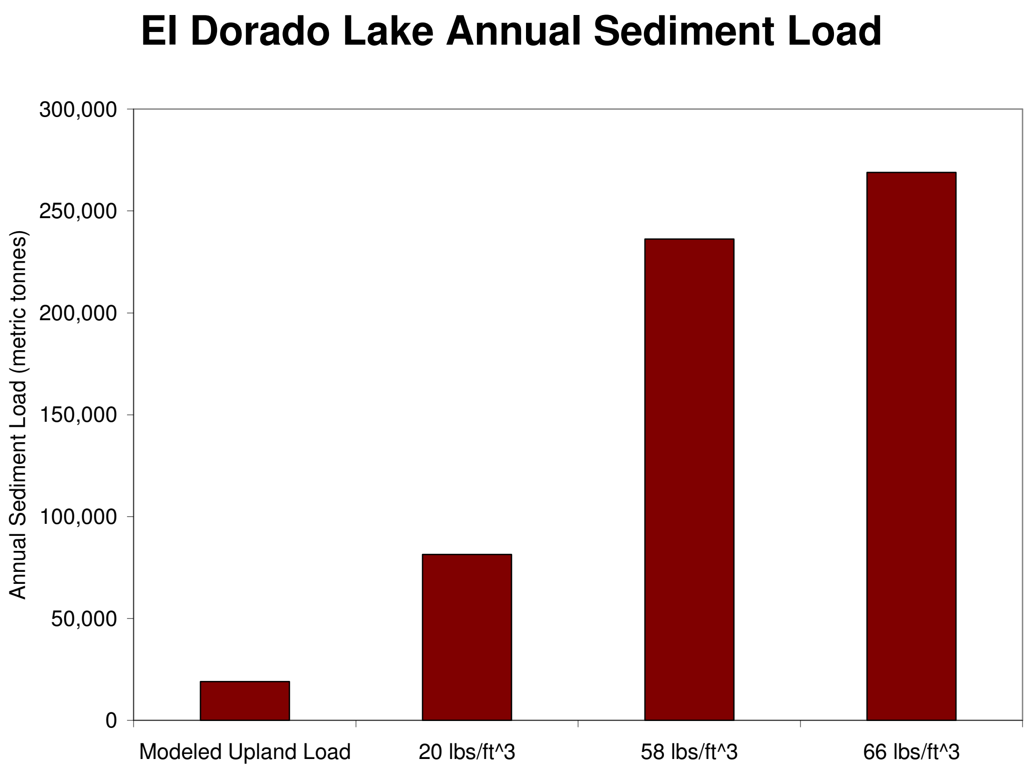

Figure 4- Estimates of average annual sediment load from differing calculations. Modeled upland load is from the results of the SWAT model developed by CoE. The remaining three bars are differing estimates of annual load using bulk density estimates from three sources and multiplying by the average annual volume loss from 1989-2005.

Major streams entering into El Dorado Lake (defined here as streams on the Kansas Surface Water Register) are largely well buffered with mature trees in the riparian zone (Table 1, Figure 5). Trees have been documented to significantly reduce the amount of bank erosion during high flow events in Kansas (Geyer, et. al, 2003), and are a recommended practice to reduce non-point source loading to streams in Kansas (Barden, 2001). A small portion of the watershed is in cropland, which is typically located in the alluvial valleys of the streams and located on land that has low slopes (Table 2), reducing the probability that these sources are major contributors to the sediment loading in El Dorado Lake. The remainder of the watershed is largely in permanent vegetation (Table

3), typically prairie grass used for cattle grazing. Some bank erosion may be the result of bank instability generated by cattle grazing in and near upland streams. Much of the upper reaches of the watershed are captured by one of the 700 impoundments (Figure 6) in the watershed, which may capture some sediment and potentially reduce the loads traveling downstream. Clarification of the sources and causes of sediment loading to El Dorado Lake will be needed to better target conservation measures to reduce sediment delivery.

Permanent Grass	40%
Wetlands	31%
Forest	20%
Cropland	5%
Other	5%

Table 1- Land use within 100 ft of registered streams in the El Dorado Lake watershed. Land use information was drawn from the 2001 National Land Cover Dataset.

Slope	Percent
0%	38.05%
1%	38.72%
2%	14.31%
3%	5.35%
>=4%	3.57%

Table 2- Cropland slope in the El Dorado Lake watershed. More than three fourths of the cropland has a slope of 1% or less. More than 96% of the cropland has a slope of 3% or less.

Land Use	Percent	Land Area (acres)
Grassland/Herbaceous	81.08%	126,860
Open Water	6.54%	10,229
Cultivated Crops	5.40%	8,446
Developed	2.92%	4,565
Forest	2.46%	3,853
Wetland	1.61%	2,517

Table 3- Land use in the entire El Dorado Lake watershed. Land use information was drawn from the 2001 National Land Cover Dataset.

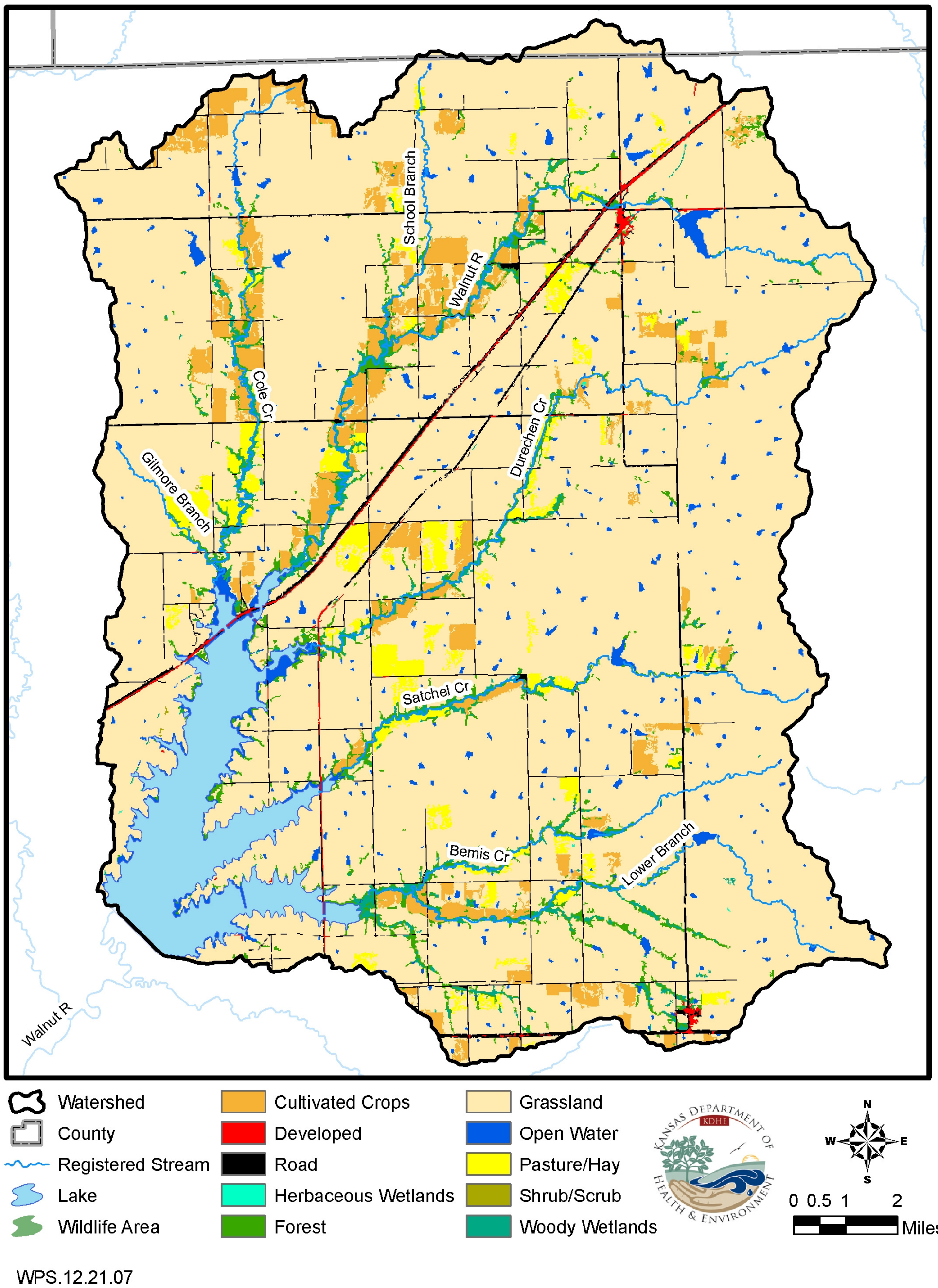

Figure 5- Land use in the El Dorado Lake watershed. Green areas along registered stream represent forested riparian areas.

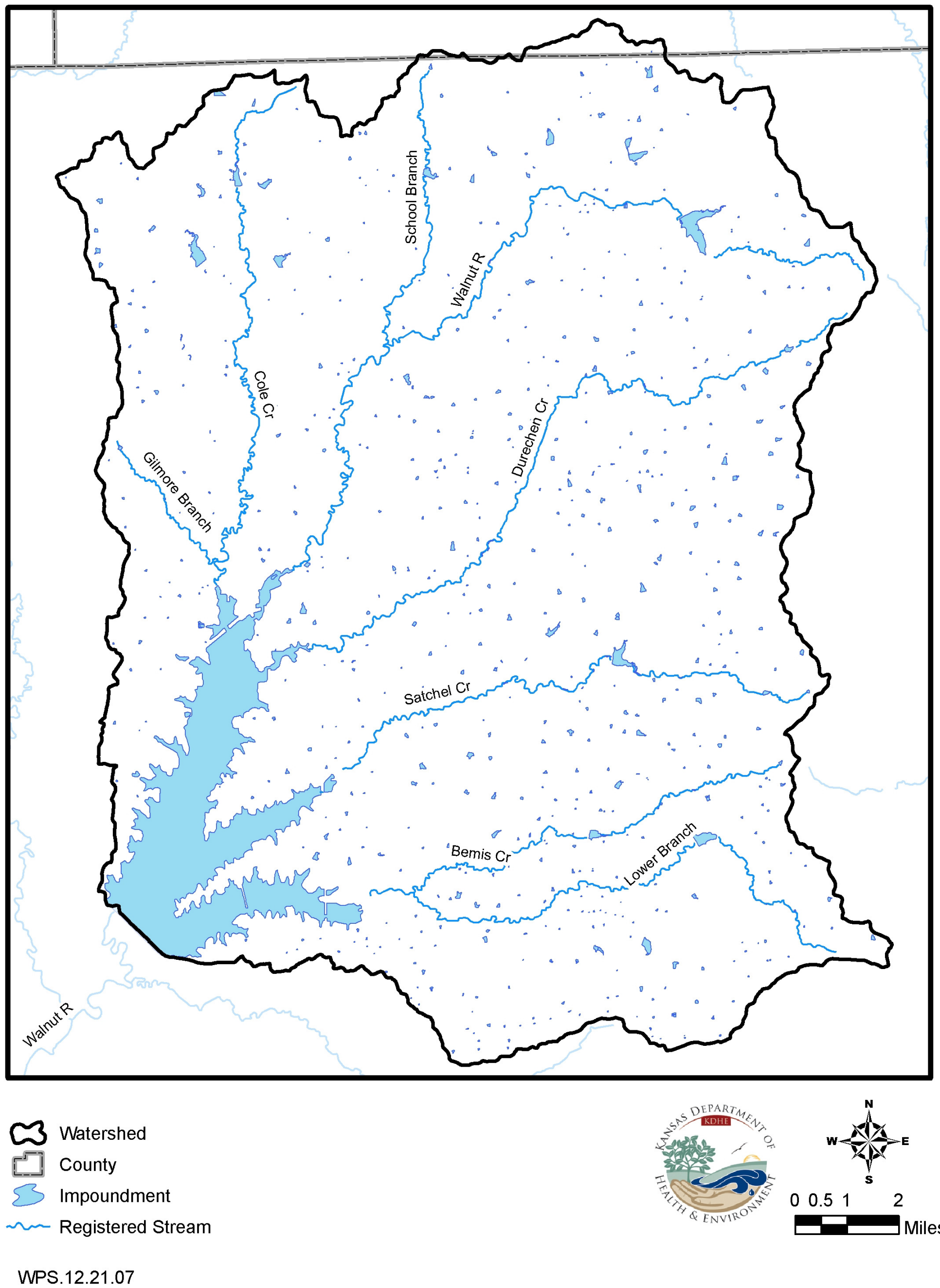

Figure 6- Locations of the 700 impoundments in the El Dorado Lake watershed. Mapped disconnects between major streams and large impounds are due to an error in geospatial layers, and do not reflect actual channel locations on the ground.

Eutrophication- The 2002 eutrophication TMDL was developed to protect the lake from loss of beneficial uses due to increased trophic state. While evidence at that time indicated that the lake was below the general guidance of 12 µg/l chlorophyll A (Figure 7), the agency was concerned that a successful reduction of the TSS concentration resulting from the siltation TMDL could result in increases in chlorophyll concentrations over the recommended guidance. Unbeknowst to anyone at that point, zebra mussels had already invaded the lake, and the coming years saw a significant increase in clarity (measured as secchi depth) (Figure 8) and an increase in chlorophyll concentrations (Figure 7). While the last measured concentration of chlorophyll was below our current guidance for public water supply lakes of 10 µg/l chlorophyll A, a review of the limited available data suggests that the lake could benefit from an increased focus on efforts to reduce nutrient loads entering the lake.

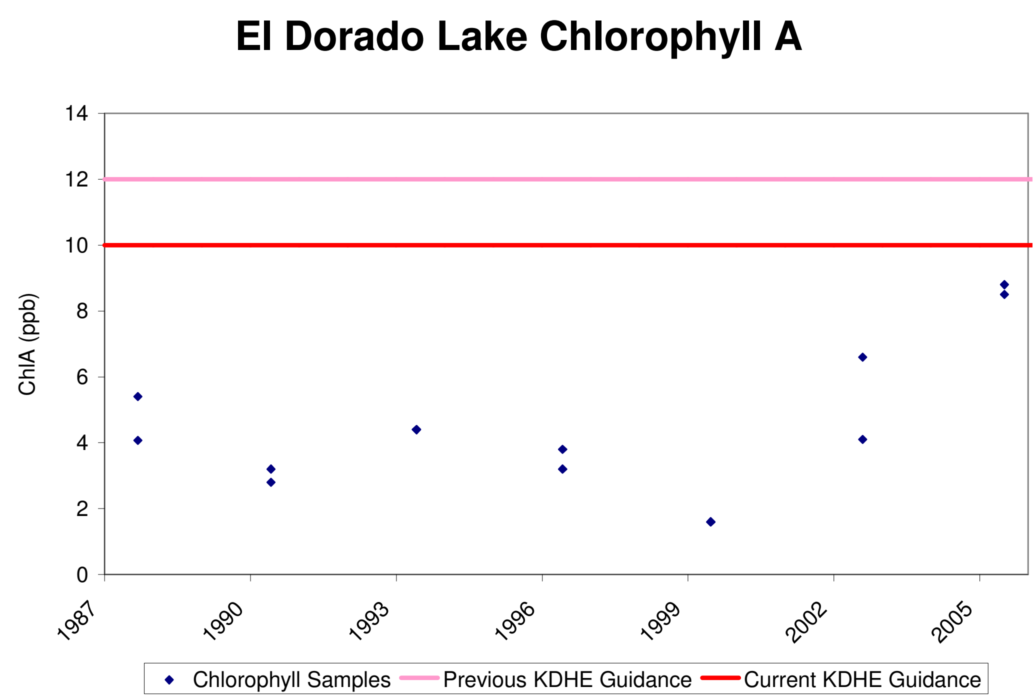

Figure 7- Chlorophyll A concentrations (ppb) in El Dorado Lake during KDHE sampling events.

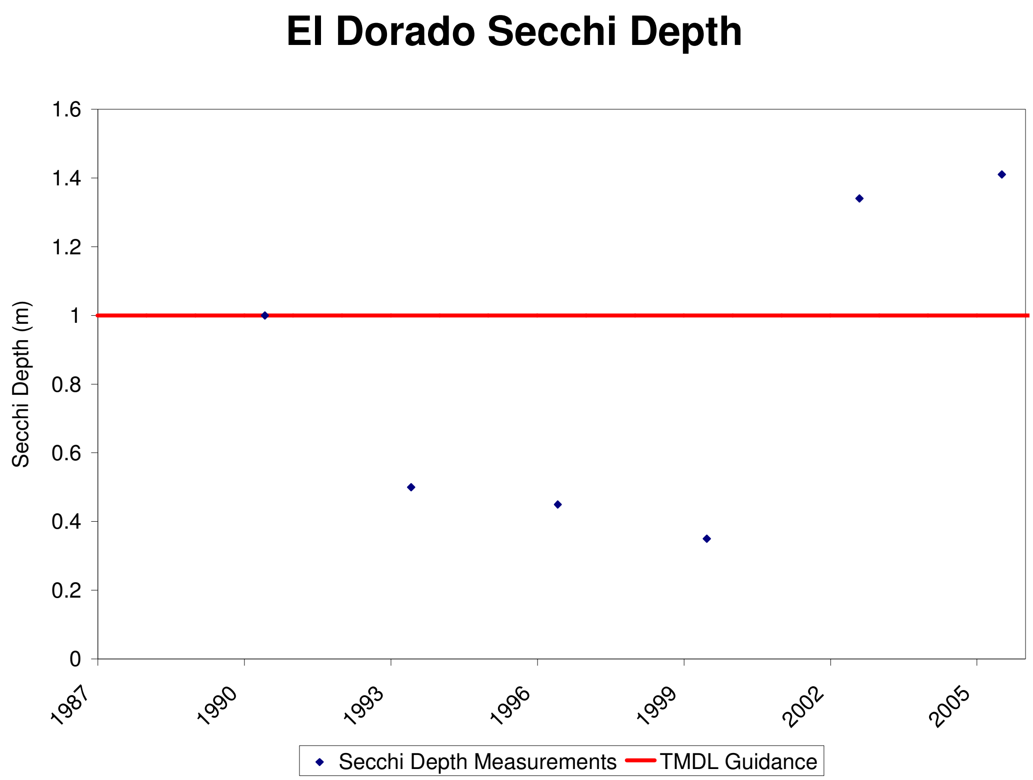

Figure 8- Secchi depth measurements in El Dorado Lake during KDHE sampling events. The 2002 TMDL established an interim goal of secchi depth greater than 1 m.

The 2002 TMDL established load allocations for phosphorus, and interim endpoints for secchi depth (>1m), total nitrogen (<0.62 mg), and chlorophyll A (<12 μg/l). While the TMDL did not specify a total phosphorus concentration expected to result in improvements to water quality, we can see that the interim endpoints have been met (Figures 7, 8 and 9), total phosphorus concentrations have gone down to the current detection limit for KDHE analysis (20 μg/l) (Figure 10), and an increase in chlorophyll A has been observed (Figure 7). These result suggest that our ability to accurately characterize the character of the trophic state in El Dorado Lake is limited by an incomplete understanding of the interacting factors resulting in the observed condition.

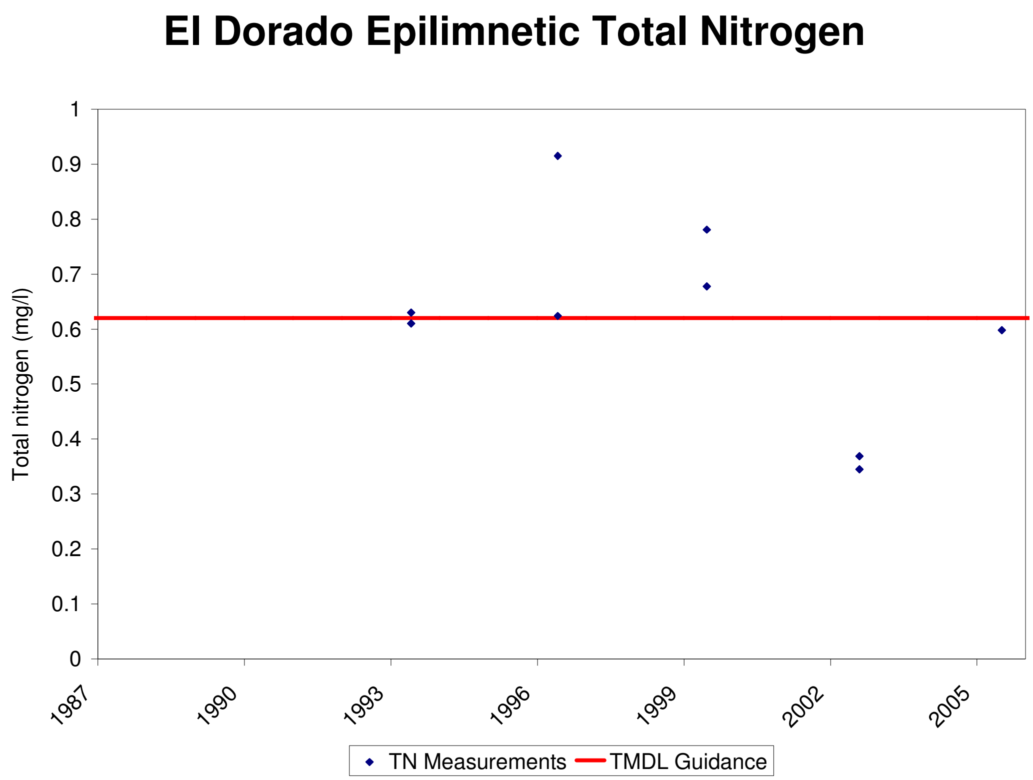

Figure 9- Total nitrogen concentrations in El Dorado Lake during KDHE sampling events. The TMDL established an interim goal of 0.62 mg/l total nitrogen.

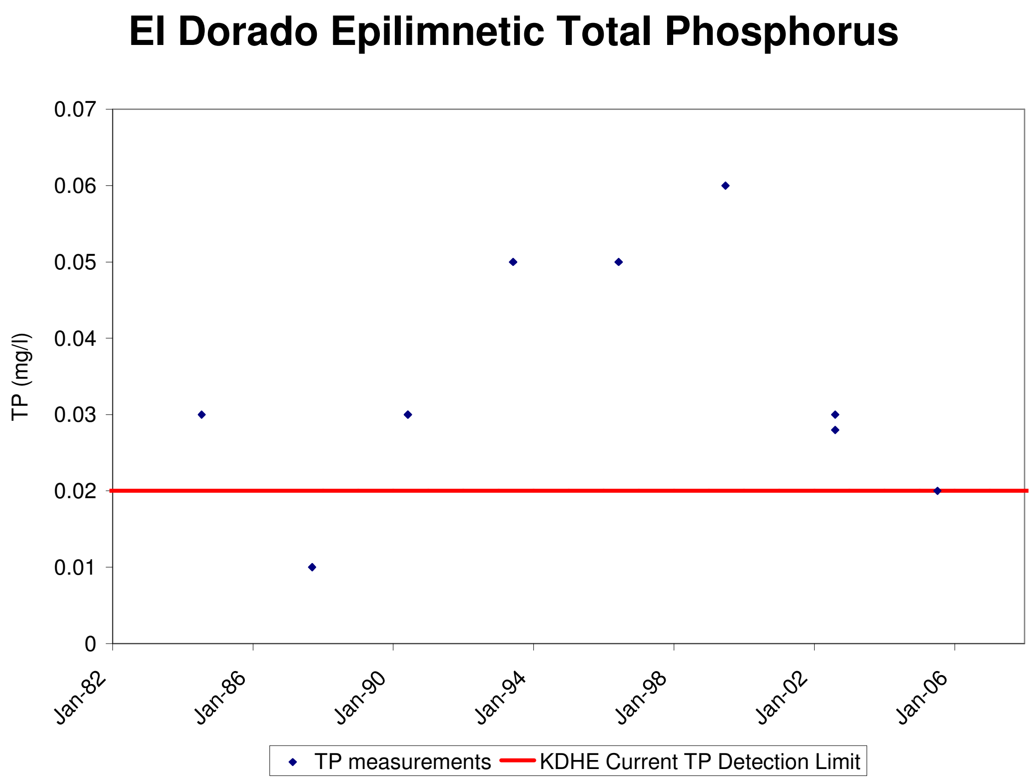

Figure 10- Total phosphorus concentrations in El Dorado Lake during KDHE sampling events. The current KDHE total phosphorus detection limit is 0.02 mg/l.

Using inflow data from CoE estimates for the period of available record (11/1994-12/2005) concurrent with KDHE samples (Figure 11) shows that nearly 40% of the time no water is flowing into El Dorado Lake (Figure 12). Long term fluctuations show that this lake receives highly sporadic flows (Table 4 and 5), consistent with the shallow bedrock formations within its watershed. These kinds of high flow events could result in either an increase or a decrease in chlorophyll concentrations depending on the lag time need to respond to increased available nutrients, dilution effects, and lake management activities including releases. Similarly, low flow periods could result in either reduced suspended sediment with a concurrent increase in chlorophyll concentrations, or the less likely, but not precluded, possibility of reduced nutrient availability and lower chlorophyll concentrations. An examination of the flow in the 90 days prior to KDHE sampling events shows no clear trend to help identify potential linkages to chlorophyll concentrations (Figure 13 and 14).

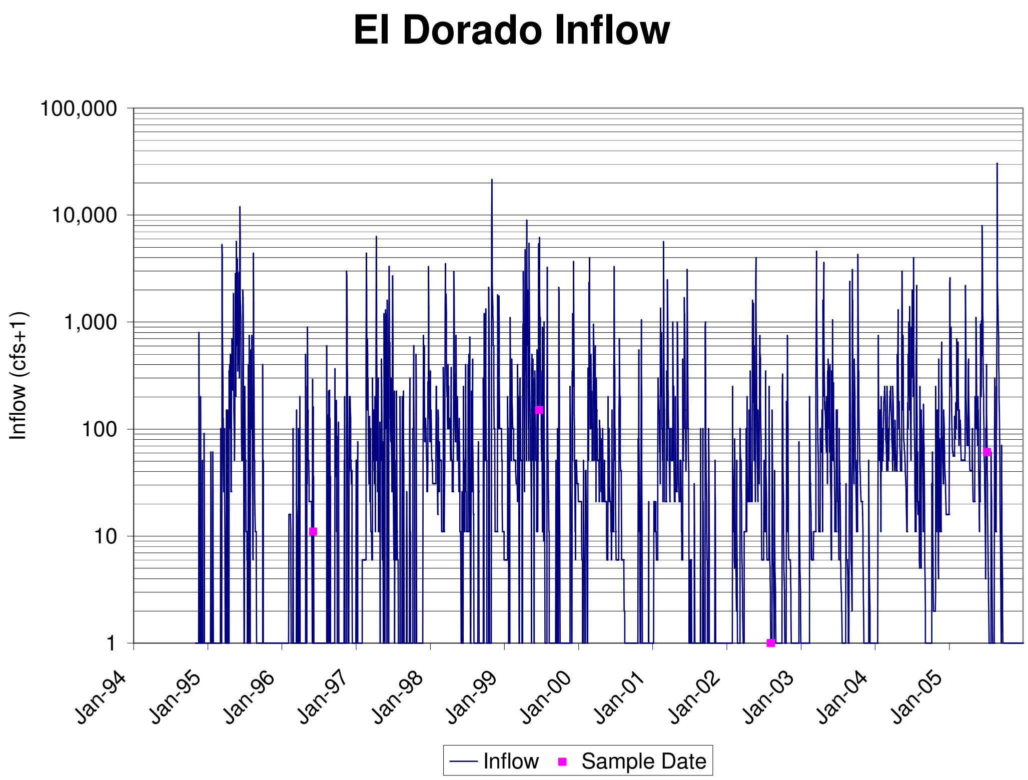

Figure 11- CoE inflow data from 11/1/1994-12/31/2005. Flow data in cubic feet per second plus 1 additional cubic foot per second for log scale plotting.

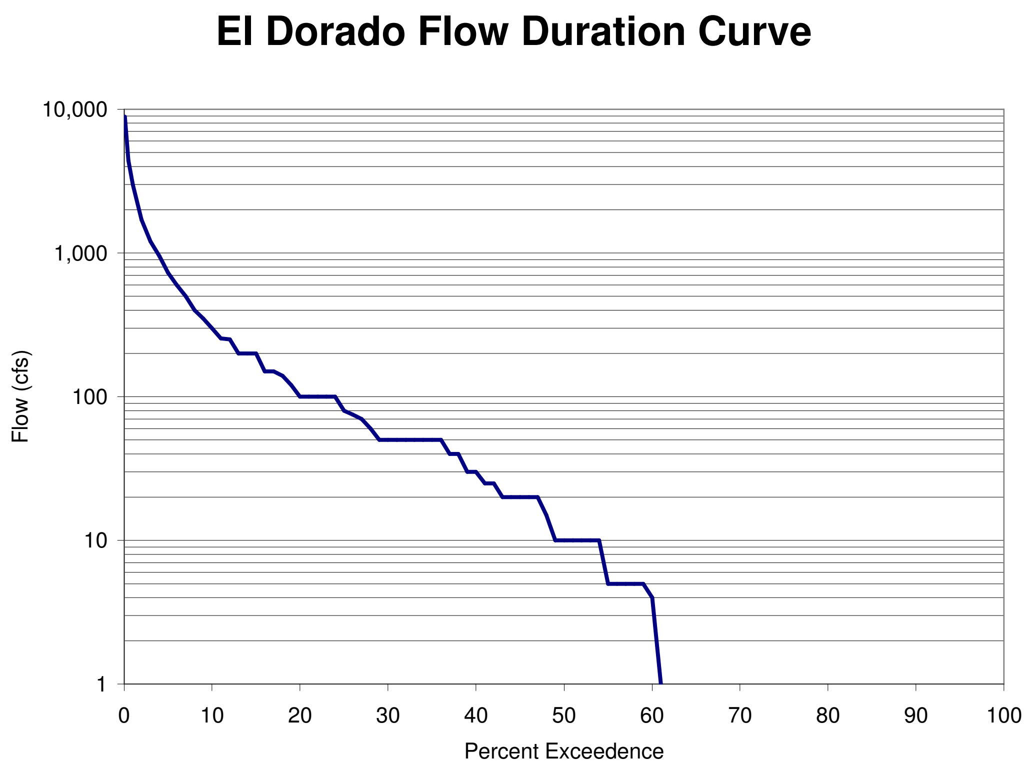

Figure 12- Flow duration curve based on CoE inflow data from 11/1/1994-12/31/2005.

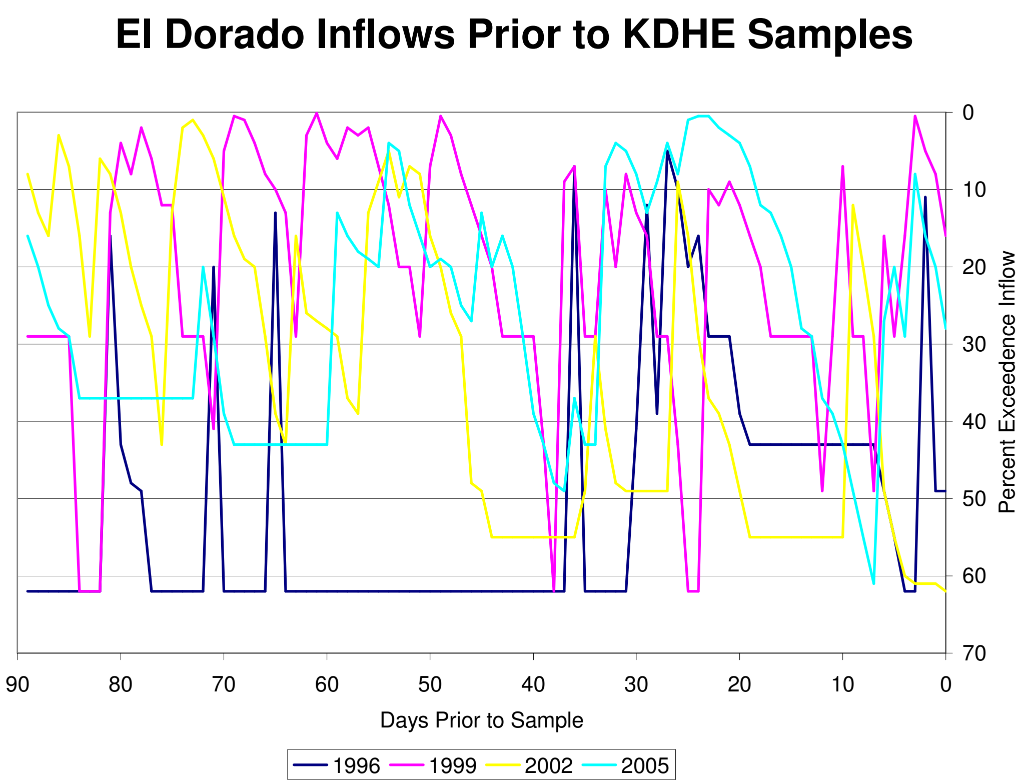

Figure 13- Inflow to El Dorado Lake for the 90 days prior to KDHE sampling events.

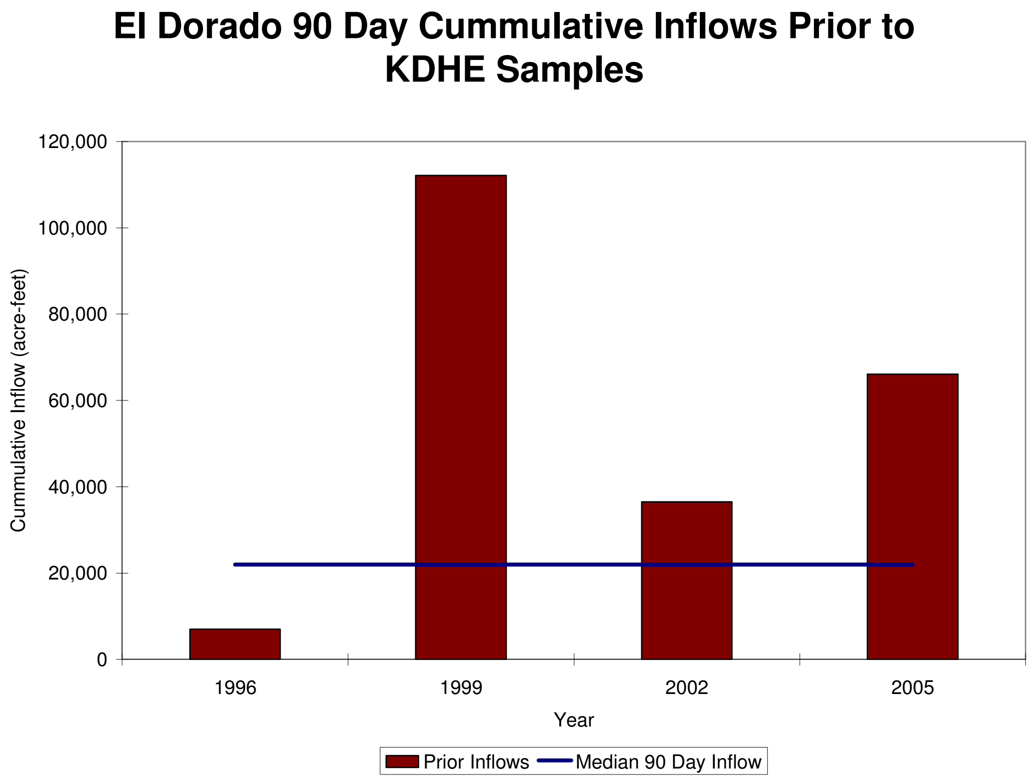

Figure 14- Cumulative inflow to El Dorado Lake for the 90 days prior to KDHE sampling events. Median 90 day cumulative flow provided for reference.

Extreme Flow Parameters	Medians	Coeff. of Disp.
Extreme low peak	0	0
Extreme low duration	6.5	1.231
Extreme low timing	235	0.1148
Extreme low freq.	7.5	1.433
High flow peak	325	0.9231
High flow duration	5	0.8
High flow timing	153	0.1694
High flow frequency	14	0.3571
High flow rise rate	165	0.6667
High flow fall rate	-96.67	-0.835
Small Flood peak	7150	0.4668
Small Flood duration	22	0.6648
Small Flood timing	107.5	0.1523
Small Flood freq.	0.5	2
Small Flood riserate	845.3	1.426
Small Flood fallrate	-709.6	-0.6453
Large flood peak	30500	
Large flood duration	20	
Large flood timing	238	
Large flood freq.	0	0
Large flood riserate	6098	
Large flood fallrate	-1906	

Table 4- Extreme flow parameters as calculated from CoE inflow data from 11/1/1994-12/31/2005 using Indicators of Hydraulic Alteration software (Version 7.0.3)

Annual Extreme Flows	Medians	Coeff. of Disp.
1-day minimum	0	0
3-day minimum	0	0
7-day minimum	0	0
30-day minimum	0	0
90-day minimum	12.09	3.256
1-day maximum	4450	1.562
3-day maximum	2508	2.331
7-day maximum	1358	2.002
30-day maximum	516.2	1.79
90-day maximum	318.5	1.368
Number of zero days	130	0.7865
Base flow index	0	0

Table 5- Annual extreme flow median values as calculated from CoE inflow data from 11/1/1994-12/31/2005 using Indicators of Hydraulic Alteration software (Version 7.0.3)

The city of El Dorado provided data on the quality of water reaching their inflow pipe for the municipal drinking water plant, which shows a general trend associated with increased productivity over time. In particular, pH measurements during the summer months have been more basic since the introduction of zebra mussels (Figure 15), even as the measured nitrate concentrations have be relatively lower (Figure 16). However, measurements of only inorganic forms of nitrogen may miss the mark when significant amounts of the total nitrogen pool is in active use by the resident biota (Dodds, 2003). Similarly, no measurements for raw water supply were taken to document phosphorus concentrations, either phosphate or total phosphorus. The lack of these critical pieces of information reduces our ability to make accurate judgments regarding the factors contributing to the observed rise in chlorophyll during the two most recent sampling periods.

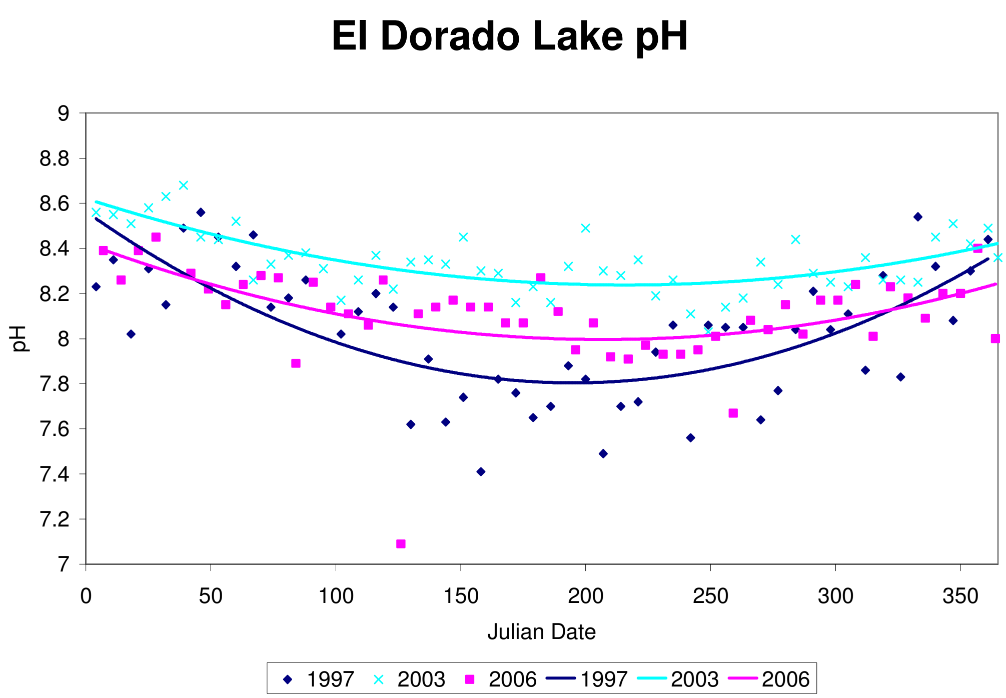

Figure 15- El Dorado city raw water intake pH data from prior to zebra mussel establishment and afterwards.

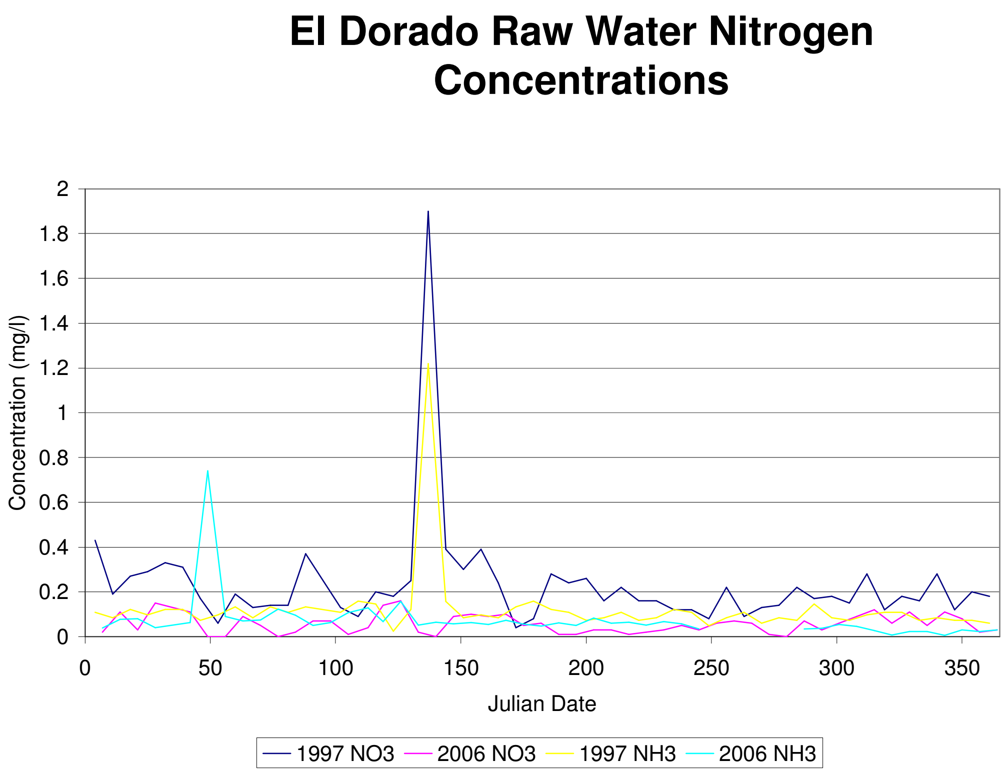

Figure 16- El Dorado city raw water intake nitrogen data from prior to zebra mussel establishment and afterwards.

Overall El Dorado Lake continue to meet KDHE expectations for water quality in a public water supply lake, but shows possible trends towards non-compliance that could indicate a declining water quality that could result in non-support designations for both drinking water supply uses and primary contact recreation. Future monitoring may provide better information regarding the changing quality of water in this water body.

Zebra Mussels- Special concern should be noted due to the presence of zebra mussels in El Dorado Lake (Figure 17). Zebra mussels not only are correlated with an increased clarity, they are also well documented selective filter feeders (citation). In many lakes where they are present the algal community has exhibited a shift from green algae to cyanobacteria, including the potentially toxic microcystis species (citation). Zebra mussels have been documented to consume other phytoplankton, while expelling cyanobacteria back into the water column undamaged. The results of this shift in algal community may pose additional serious threats to the future use of this lake as a public water supply source.

Figure 17- In late 2003 managers at El Dorado Lake lowered water levels to kill zebra mussels. While the effort failed to reduce the zebra mussel population, it did expose large conglomerations of zebra mussels, like those shown here. Photograph courtesy of the Kansas Department of Wildlife & Parks.

Zebra mussels are a non-native aquatic mussel species that were first documented in El Dorado Lake in 2003 (KDWP, 2007). Originally from the area around the Caspian Sea in central Asia, this species has spread around the globe over recent decades through ballast water in international shipping and subsequent transport to new waters. This species of mussel differs from native Kansas unionid mussels by having no intermediate host species during their life-cycle. Once established in a water body they are unlikely to be removed on a permanent basis under conditions observed in Kansas waters. While some localized extinctions have occurred in Eastern Europe, they have occurred only in lakes suffering massive industrial pollution, including heavy metals contamination (citation). One example of an extirpation has occurred in the United States, in an abandoned mine-pit lake in Virginia, by use of elevated concentrations of potassium chloride (VDGIF, 2006). These strategies are unlikely to be acceptable to Kansas water users, or viable in flow-through lakes like El Dorado, so the official policy of the Kansas Department of Wildlife and Parks is to help reduce the spread of zebra mussels to new locations while engaging in no additional activities to manage existing populations (Goeckler, J., personal communication, 2007). New populations have been observed in other Kansas waters since their documentation in El Dorado Lake, including nearby Winfield City Lake, Cheney Lake & Perry Lake.

The exact impact on water uses at El Dorado Lake from the zebra mussels remains unclear, though it is reasonable to assume that reductions in nutrient concentrations from TMDL implementation will result in reduced available food supply for these organisms. Maintaining low populations of zebra mussels at El Dorado Lake has multiple benefits, including reduced costs associated with cleaning and maintaining intake pipes, outlet works and other permanent structures.

Land use- Land use in the watershed is predominantly permanent grass. Limited cropland exists in the watershed, and is primarily concentrated in the alluvial valleys of the major streams. These streams are typically well buffered by mature trees and on low slope land, which should mitigate some of the impacts of row crop agriculture (Figure 5 and Tables 1 and 3). Additional efforts to expand the buffers to include permanent grass may have some impact on the nutrient and sediment loading to El Dorado Lake. However, many of the lands in production are low soil rental rate areas (Figure 18), resulting in limited interest by local producers in cost-share programs. Additional financial incentives to supplement cost share programs may result in increased buffering of these lands.

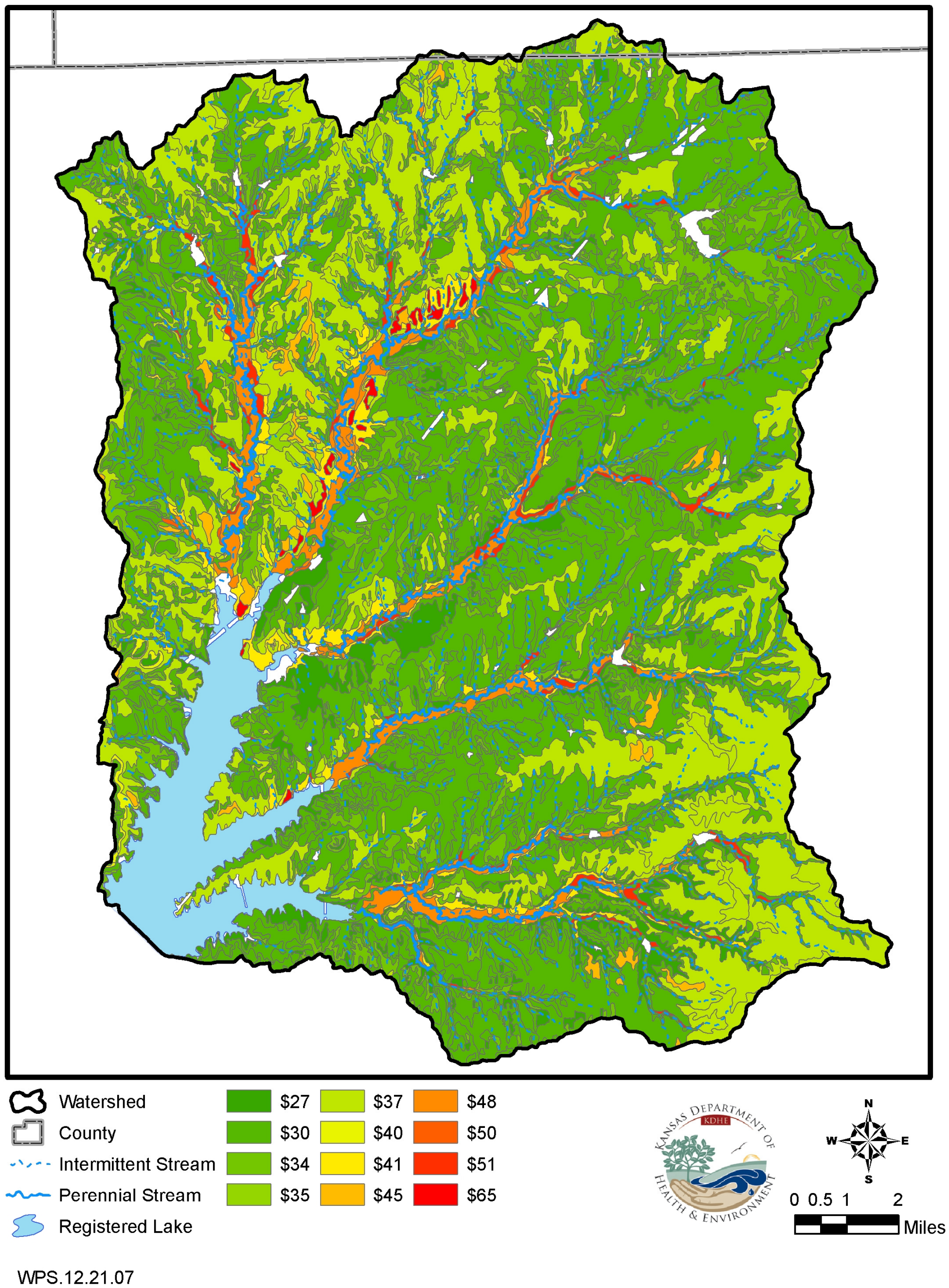

Figure 18- Cost share 2006 soil rental rates for the El Dorado Lake watershed. White areas are beneath impoundments that are not on the Kansas Surface Water Register or other non-agricultural lands.

Upland areas are largely in permanent vegetation, primarily used for cattle grazing (Figure 5). Cattle populations in Butler County have changed with changing annual rainfall, reflecting alteration of grazing pressures with forage reductions (Table 6). The average number of acres per cattle are lower than recommended by KSU Research & Extension (Ohlenbusch & Watson, 1994) suggesting that in some areas of Butler County there is overgrazing. The possibility that overgrazing is occurring in the El Dorado Lake watershed cannot be discounted.

Year	Cows All	Calf Crop	Cattle All	Beef Cows	Milk Cows	Cattle on Feed All Lots	All Cattle Minus All Cows	Acres Grazing Land/Animal
1990		22,600 head	119,000 head	22,800 head	1,300 head			5.496731
1991		22,700 head	118,200 head	22,900 head	1,150 head			5.533934
1992		23,200 head	112,400 head	23,900 head	850 head			5.819493
1993		23,200 head	117,300 head	24,400 head	650 head			5.576394
1994	26,250 head	25,400 head	122,200 head	25,600 head	650 head		95,950 head	5.352791
1995	27,700 head	24,500 head	123,400 head	26,800 head	900 head		95,700 head	5.300737
1996	25,400 head	24,800 head	119,500 head	24,800 head	600 head		94,100 head	5.473732
1997	25,800 head	21,800 head	120,000 head	25,200 head	600 head		94,200 head	5.450925
1998	23,400 head	21,400 head	125,000 head	22,800 head	600 head		101,600 head	5.232888
1999	22,900 head	19,500 head	121,000 head	22,500 head	400 head		98,100 head	5.405876
2000	21,000 head	19,100 head	119,000 head	20,600 head	400 head		98,000 head	5.496731
2001	20,600 head	23,000 head	116,000 head	20,100 head	500 head		95,400 head	5.638888
2002	26,900 head	24,400 head	102,900 head	26,500 head	400 head		76,000 head	6.356764
2003	24,950 head	23,900 head	98,000 head				73,050 head	6.674602
2004	24,400 head	23,300 head	100,000 head	24,000 head	400 head		75,600 head	6.54111
2005	24,350 head	21,100 head	96,600 head				72,250 head	6.771335
2006	21,800 head	24,600 head	100,900 head				79,100 head	6.482765
2007	23,900 head		110,000 head	23,600 head	300 head		86,100 head	5.946464

Table 6- Cattle populations in Butler County, KS from the National Agricultural Statistics Service.

While no numbers are available to us at this time, if conditions are similar in this watershed to other locations in the state, cattle likely have free access to the many ponds and upland stream channels in the watershed. Provision of alternate watering sites have been documented to reduce the impact of cattle grazing on aquatic ecosystems by reducing both direct inputs of nutrients (defecation) and the increased stability of streambanks with less resulting erosion during large storms. Line et. al (2000) documented substantial improvements in nutrient and sediment concentrations after excluding cattle and restoring riparian vegetation. Improvements in cattle grazing management has also been correlated with increased base flow and reduced runoff, both of which may provide additional benefits to El Dorado Lake.

The 2002 TMDLs identified the following activities as recommended implementation measures.

1. Implement soil sampling to recommend appropriate fertilizer applications on cropland.
2. Maintain conservation tillage and contour farming to minimize cropland erosion.
3. Install grass buffer strips along streams.
4. Reduce activities within riparian areas.
5. Implement nutrient management plans to manage manure application to land.

Implementation efforts since the adoption of the TMDL have been limited. Previously mentioned soil rental rates (Figure 18) may be a contributing factor. Since 2002 twenty seven implementation efforts have request cost-share assistance, and 19 of the efforts have been funded. Some of those efforts have included livestock waste systems, well decommissioning, fencing and pipeline. More than half of the implementation dollars approved went to two projects, a streambank protection effort and a wastewater treatment lagoon. Other efforts have included range planting, wetland creation, watering locations, a grassed waterway and an onsite wastewater treatment system.

In 2002 a Phase III Water Quality Protection Project was started with $21,999.36 of grant funding to improve water quality in the El Dorado Lake watershed. This grant was completed in 2004, and focused on an information and education program to "familiarize citizens with issues and concerns regarding non-point source pollution and protecting water quality (Koontz, 2006)." This effort included numerous contacts with landowners, tours of conservation practices, newsletters and other education activities. The final grant report (Koontz, 2006) indicated that the Butler County Conservation District was planning on applying for a new grant through the Watershed Restoration & Protection Strategies (WRAPS) program in fiscal year 2007 for a project beginning fiscal year 2008 to implement a five-year plan to increase implementation of unmet needs. They deferred application for new WRAPS funding pending the recent completion of the Corps feasibility study. At this time no decision has been made regarding whether to apply for new WRAPS funding for future projects. There remain unmet needs, including increased filter strips adjacent to riparian areas, streambank stabilization, livestock waste management upgrades, nutrient management plans, terracing, grass waterways, and other practices to reduce sediment and nutrient loading to El Dorado Lake.

While these efforts are laudable, they have not yet proven enough to maintain El Dorado Lake at the low chlorophyll concentrations observed before the implementation of these TMDLs. Improvements to, and increases in, implementation efforts in the El Dorado Lake watershed can be expected to continue providing improvements to water quality in this lake. Partnering programs between urban water users and rural land managers have proven successful in other Kansas communities, and may provide a model for future efforts to increase adoption of best management practices.

Citations-

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